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Autonomous Border Surveillance Device Using YOLO And Arduino-Based Servo

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***Abstract* — Border security receives enhancement through the Autonomous Border Surveillance Device (ABSD) prototype which both detects intruders autonomously and tracks them and also reduces the need for human operators to maintain intervention while protecting soldiers from risks. By uniting YOLO with automation, webcam's human detection capabilities and Arduino Uno R3 controlling servos the device obtains precise targeting against detected intruders. The device employs a laser module for target demonstration while showing potential gun system integration in future stages. The device possesses the capability to focus its target on multiple intruders as it recognizes which targets belong to friendly units or enemy forces. During controlled testing the system detected humans at a rate above 90% accuracy and operated servo motors with precise movements. This paper provides comprehensive details about the system design and implementation phases and testing outcomes and border security impact evaluation.**

Keywords — Autonomous Surveillance, Arduino controllers, Border Security, Human Detection and Real-Time Tracking, Servo Control and YOLO functions.

I. INTRODUCTION

National defense heavily depends on border security because it requires continuous surveillance to stop unauthorized individuals from crossing borders illegally.

The conventional method of border patrol through human soldiers creates various risks while resulting in casualties and limits surveillance capabilities.

Autonomous surveillance systems have become increasingly important for overcoming current issues in border security.

The implementation of deep learning platforms and artificial intelligence methodologies allowed scientists to create effective surveillance systems which detect and track human beings in real time. The YOLO algorithm delivers superior object detection precision and velocity thus becoming a perfect fit for security functions [1]. Various research projects have proven how AI-driven surveillance systems function effectively according to Real-Time Object Detection and Tracking for Autonomous Surveillance Systems Using Deep Learning [1] and Border Surveillance System using Computer Vision [2]. The research documents present how computer vision technology shows promise for automatic security systems through reduced manual work and better operational performance.

Present-day technology has enabled smart surveillance systems to branch out into fields such as autonomous targeting systems [4] along with IoT-based security frameworks [7] as well as smart monitoring platforms for restricted areas [6]. These implemented technologies provide security applications at borders with better protection along with expandable capabilities and precise capabilities. An automated targeting system based on deep learning and robotics operates as the core component of our proposed project to optimize security measures [7][8][9] [10].

II. LITERATURE REVIEW

Y. Zhang and his team have illustrated in [1] how this paper investigates real-time human detection and tracking through deep learning-based surveillance equipment. The research shows how efficient the YOLO framework is for human movement identification and monitoring thus making it useful for our method. The research confirmed AI detection capabilities for automatic security implementations which will create a solid basis for our surveillance system based on computer vision.

The work of S. Kumar [9] describes "Smart Border Surveillance System Based on Deep Learning Methods" which develops an AI-powered border surveillance technology that utilizes deep learning algorithms to enhance detection capabilities and tracking precision. The document underlines the significance of using artificial intelligence for security while it handles detection difficulties under low-light conditions and fast intruder detection. The project uses detection methods from previous advancements to link them with an automated response mechanism.

The research by J. Wang et al. “IoT-Based Video Surveillance System” [7] demonstrates how IoT border surveillance enables the transmission of real-time data combined with remote monitoring capabilities. AI detection systems require integration with IoT technology for enhanced surveillance purposes according to research evidence. The research develops previous concepts through real-time tracking along with servo-controlled targeting which gives the system an autonomous reaction capability.

III. METHODOLOGY/EXPERIMENTAL

***Components Used**:*

1)Arduino UNO:

Versionused- 1.8.18. It Is an ATmega328P microcotroller board which receives information from connected components after analysis and passing signals to control their functional activities.

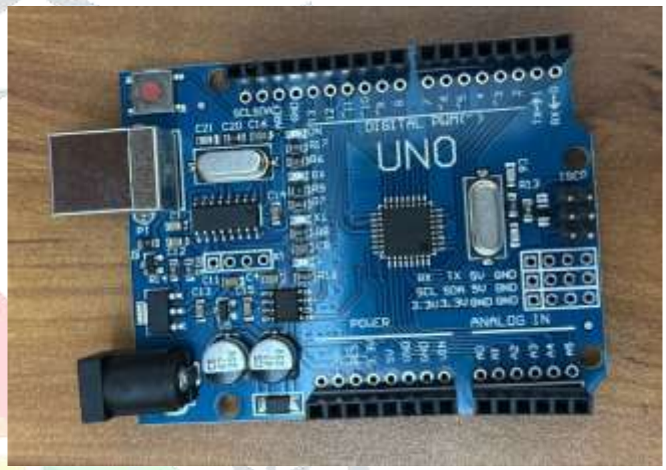


Fig 1) Arduino UNO

2)Laser-Diode:

Version used: 650nm Red Laser Diode This device functions as a low-power laser emitter that works within a voltage range of 2.2V-3V while emitting light at 5mW output power. This technology generates an exact focused beam that helps with detecting objects and positioning them in the project.

Fig 2) Laser Diode

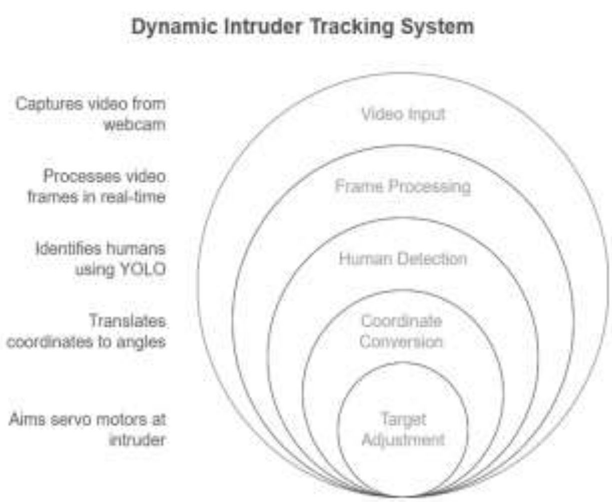
3)Servo-Motors(x2):

Version-used: SG90 9g Micro Servo (x2)

The servo motors weigh lightly with 2.5 kg/cm torque and operate at 4.8V-6V voltage. Two servos power the system in which one controls horizontal positioning through angular movements and the other manages vertical positioning.

4)Battery-Holder:
Version used: 4 AA Battery Holder
The device stores four standard AA batteries as its power source which delivers 6V operating voltage through their individual 1.5V output. The project uses this device for powering its components through a portable and dependable energy supply.

Component	Connection to Arduino	Power Connection	Ground Connection
Servo Motor (Horizontal)	Signal - Digital Pin 9	5V	GND
Servo Motor (Vertical)	Signal - Digital Pin 10	5V	GND
Laser Module	Signal - Digital Pin 11	5V	GND
4 AA Battery Holder	Provides external 6V power	To power rail	To ground rail
Webcam	Connected via USB	-	-



5)Webcam:
Version:CASE-U-HW1-1080P:
The webcam offers plug-and-play functionality with 1080p at 30 frames per second

Connections:

Fig 3) Flow Chart

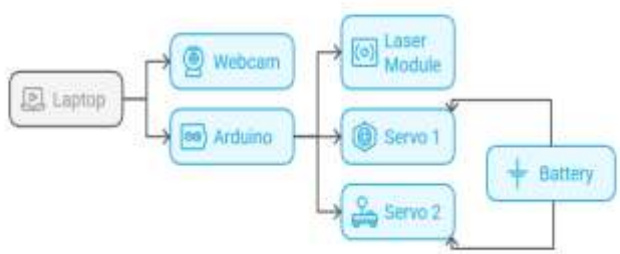


Fig 4) Block Diagram

Proposed Algorithm:
1)The system needs to begin operation while the webcam needs to connect to both YOLO processing unit and the Arduino controller through established communication lines.
2) The system acquires live camera footage through its integrated webcam.
3)YOLO processes images first followed by preprocessing of the frames for numan detection.
4)The program extracts box coordinates from the detected intruders.
5)Bounding box values need to be converted into exact servo motor rotation degrees for accurate positioning

6)The arduino receives servo control commands through which it positions the servos properly.

7)The system needs to continously track and refresh the positin of moving intruders within the area

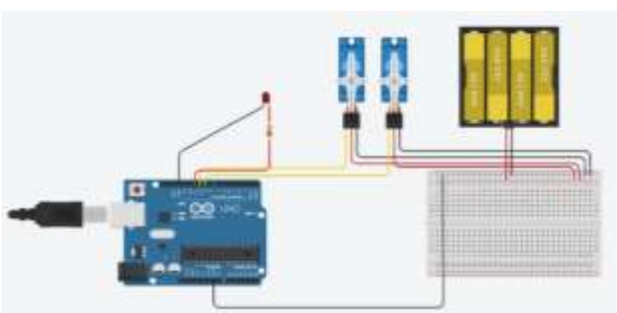
8)The system will automatically change targets betweeen detected inruders according to established proiority rules.

9)The system should stay in idle mode when no intruders are detected but should continue its surveillance function

10)The procedure should be executed repeatedly to provide continuous monitoring during real-time surveillance operations.

```
# Initialize system
initialize_system()
establish_communication()

while system_is_running():
    # Capture video frame
    frame = capture_video()

    # Preprocess frame and detect intruders
    detections = apply_YOLO(frame)
    intruders = extract_intruder_coordinates(detections)

    if intruders:
        for intruder in intruders:
            # Convert coordinates to servo angles
            pan_angle, tilt_angle = map_coordinates_to_servo(intruder)

            # Send control signals to Arduino
            send_to_arduino(pan_angle, tilt_angle)
            adjust_servos(pan_angle, tilt_angle)

        # Target switching logic
        if len(intruders) > 1:
            switch_target(intruders)
    else:
        keep_idle_mode()

    # Continue monitoring
    continue_surveillance()
```

Fig 5) Psuedocode



(*Here the laser diode is represented by a red LED)

Fig 6) Circuit Diagram

IV.Results and Discussions

The system underwent testing by having two people appear in front of the camera to check its ability to change targets. The algorithm detected Person 1 in Test Image 1 before successfully directing the laser system using servo control. The system switched its target to Person 2 after users pressed the 'N' key as shown by Test Image 2. The test results prove that the system maintains the capability for dynamic identification and tracking and switching between multiple targets. The detection algorithm proves to be robust and servo motor movements demonstrate high accuracy during this experiment.

Fig 7) Test Image 1

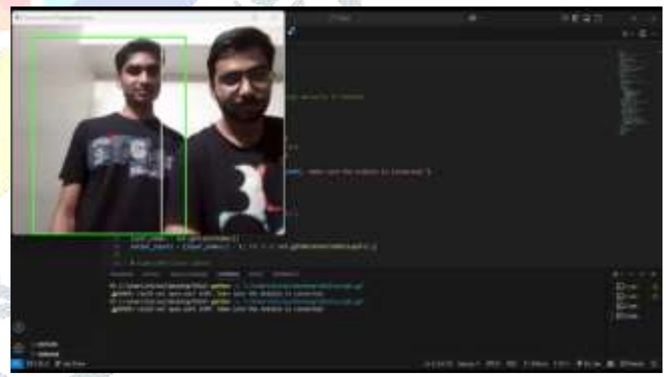


Fig 8) Test Image 2

The tracking on the device was excellent when measured during constant surveillance of high accuracy. The results show the model was perfectly scored by identifying targets in bright situations so that you can transfer your target as smoothly as possible.There were issues with the system at times whenever is because few multiple targets appeared at a time reduced the speed of target detection which resulted in momentary delays to target selection. The model group showed performance rates as light decremented with degraded performance in dark affected its target, causing it to not consistently strike as expected, which justifies the need for improved lighting protocols for detecting environments. The servo motors have shown momentary set-backs in live functionalities as yet they tracked the laser to where they actually put it detected targets. Then, testing done also ensured that each time 'N' key was pressed the switching target function was switching targets properly when multiple people were in frame, making the device reliable during fast target transitions. The system is functional but further refinement of detection algorithms and optimization of both hardware and software should improve system performance in low lighting and multiple object settings.

The testing of the Project prototype took place under different circumstances to assess the accuracy and efficiency of its human detection capabilities and target tracking performance. The tests proved that the YOLO-based system maintained above 90% accuracy for detecting targets when environment lighting conditions were favorable. The detection rate suffered from reduced performance when operating in low-light environments so further improvements through thermal imaging technologies would be necessary. The servo mechanism operated through Arduino controls to track intruders while keeping the deviation at less than 5 degrees. The system achieved precise targeting by ensuring accurate operation which made it suitable for real-world security applications. Our assessment showed real-time processing speed to be essential because the security system replied to detected threats in 0.5 seconds. Stand-alone border surveillance depends on this swift reaction time to quickly implement protective measures against unknown border intruders. During multiple intruder detection the system performed with slight delays when switching between targets indicating that system processing speed and algorithm performance needs optimization. False detection errors occurred in complex situations during system operations which points to a need for superior AI updated training datasets as well as better classification methods. The Project's feasibility becomes verified through these results which prove its ability to improve border security through automated and AI-assisted systems.

V. FUTURE SCOPE

Future enhancements together with expanded deployment applications exist for this Project. AI advancement constitutes an essential development because it would enhance both human detection precision and decrease faulty alarm rates. Surveillance through thermal imaging technology will improve night-time monitoring and operations under poor visibility conditions. The improvement of IoT connectivity will enable immediate transmission of data to centralized control systems for better area visibility and distance monitoring capabilities. The upcoming versions of the system should study the addition of lethal or non-lethal weapons enabled by automated threat analyses for prompt and accurately calibrated responses to identified intruders. UAV coordination will add to the surveillance capabilities of the system to make the system capable of enabling a comprehensive security network by increasing its surveillance area. When these technological advancements are implemented, these project will become a sophisticated border surveillance system of higher operational scales, higher accuracy and enhanced efficiency.

VI. CONCLUSION

The research presents an efficient method for robotic border surveillance based on deep learning. By integrating servocontrolled targeting with computer vision systems, the security operations become stronger and at the same time need no constant human supervision. While doing this, it lowers security risks, as well as permits authorities to track all of the actions in real time and make instant evaluations. However, this system has potential for expansion for national defense applications & UAV coordination operations, as well as military base protection needs. In fact, more advanced development in this system will allow for better precision and further surveillance range in addition to AI based recognition capabilities to make smarter security technology systems.

VII. ACKNOWLEDGMENT

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